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PII: S0261-2194(97)00019-7

Crop Protection Vol. 16, No. 5, pp. 439–447, 1997
Published by Elsevier Science Ltd
Printed in Great Britain
0261-2194/97 $17.00+0.00

Comparison of four particulate substances as wildlife feeding repellents

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We compared the effectiveness of dolomitic lime, activated charcoal, Nutra-lite (a silica-based compound), and white quartz sand as feeding repellents for brown-headed cowbirds (*Molothrus ater*), white-tailed deer (*Odocoileus virginianus*), and Canada geese (*Branta canadensis*). In 4 day, two-choice aviary tests with cowbirds, consumption of treated millet (1–4% $g\,g^{-1}$) was less than consumption of untreated millet for all particulates except Nutra-lite at 1% $g\,g^{-1}$. Greatest reductions in consumption occurred with lime-treated millet, followed by charcoal, Nutra-lite, and sand. Overall mean daily consumption of treated millet by cowbirds in one-choice tests was similar to total consumption of millet in comparable two-choice tests for each particulate. However, millet treated with 4% lime reduced cowbird consumption for 1 day. Similarly, in 4 day, two-choice field tests involving free-ranging deer, deer consumed less corn treated (4% $g\,g^{-1}$) with lime or charcoal than corn treated with Nutra-lite or sand. Corn treated with sand did not reduce consumption by deer relative to untreated corn. Lime applied to turf in 10 m × 21 m enclosures at an application rate of 270 kg ha^{-1} did not suppress grazing by geese. Nutra-lite applied to turf at the manufacturer-recommended rate of 2568 kg ha^{-1} reduced overall goose presence on treated plots in enclosures for 3 days but suppressed goose grazing for 1 day only. We conclude that lime is more effective overall as a white-tailed deer and brown-headed cowbird feeding repellent than is charcoal, Nutra-lite, or sand. Lime has considerable potential as a feeding repellent in agricultural and possibly turf situations. Charcoal could be used effectively in situations where lime is impractical. Published by Elsevier Science Ltd

Keywords: activated charcoal; *Branta canadensis*; brown-headed cowbird; Canada goose; dolomitic lime; *Molothrus ater*; Nutra-lite; *Odocoileus virginianus*; particulate; repellent; white quartz sand; white-tailed deer

Populations of many species of wildlife that conflict with human activities have increased in recent years. For example, the number of Canada geese (*Branta canadensis*) in the Mississippi Flyway increased 148%, from 745 000 to 1 850 000 between 1980 and 1989 (Babcock, Humburg and Graber, 1990). Ankney (1996) stated that the resident population of giant Canada geese (*Branta canadensis maxima*) in Ontario is doubling every 5 years. Similarly, deer (*Odocoileus* spp.) populations have increased dramatically in many areas and now may number more than 26 000 000 individuals in the USA (Gladfelter, 1984; Jacobson and Kroll, 1997).

Nationwide, deer and geese cause extensive damage to orchards, tree nurseries, sprouting grain crops, and other agricultural commodities (Cleary, 1994; Craven and Hygnstrom, 1994). Additionally, use of turf at airports by geese and deer creates an unacceptable hazard to aviation. From 1993 to 1995, geese (including swans) represented about 7% of wildlife strikes with civilian aircraft in the USA (Cleary, Wright and Dolbeer, 1997). Deer represented 83% of mammal strikes with civilian aircraft (Wright, 1996).

Although populations of blackbirds have not increased in the last 30 years (Peterjohn, Sauer and Link, 1994), this group of birds also causes considerable economic loss to various crops (Dolbeer, 1994). In addition, blackbirds were responsible for 7% of wildlife strikes with US civilian aircraft from 1993 to 1995 (Cleary *et al.*, 1997).

Numerous harassment and frightening techniques are available to reduce conflicts involving geese, deer, blackbirds, and other wildlife (Dolbeer *et al.*, 1994; Marsh *et al.*, 1991). Repellents are another technique used to reduce human conflict with wildlife and can be an important component of an integrated wildlife damage management program. Considerable research has focused on the development of nonlethal wildlife feeding repellents to reduce depredations. However, few repellents, particularly those for avian species, are currently registered for use (Mason and Clark, 1992).

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Several studies have evaluated the efficacy of particulates as avian feeding repellents. Clays, plaster of Paris, Portland cement, and gypsum-based pesticide particles coated with graphite have shown some efficacy in reducing food consumption by birds (Best and Gionfriddo, 1994; Decker and Avery, 1990; Dolbeer and Ickes, 1994). Mason and Clark (1994, 1995) determined that food treated with activated charcoal or white quartz sand and turf treated with charcoal offered protection from starlings (*Sturnus vulgaris*) and snow geese (*Chen caerulescens*), respectively. Belant, Tyson, Seamans and Ickes (1997) similarly found that lime-treated grain and turf reduced consumption by brown-headed cowbirds (*Molothrus ater*) and Canada geese, respectively.

With the exception of Mason and Clark (1994), no study has compared the efficacy of particulate substances as feeding repellents. Our objectives were to compare: (1) the efficacy of three previously tested particulate repellents (lime, charcoal, and sand) and a candidate silica-based repellent, (2) the minimum effective concentration (% g g^{-1}) of these repellents, and (3) the effectiveness of these particulates between taxa (birds and mammals) in controlled aviary and field trials.

Materials and methods

Test substances

Dolomitic hydrated lime (CAS No. 59398-71-3, Genlime Group, L.P., Genoa, OH, USA) is composed primarily of $Ca(OH)_2MgO$ and has a pH of 11.7. Particle size is variable, with 99% and 67% passing through 20 and 100 mesh, respectively. This lime is commonly used as a soil amendment in turf, garden, and agricultural practices in the eastern USA. Nutra-lite (10 to ≥60 mesh; no CAS number; Montana Mineral Products, Clinton, MT, USA) is produced from volcanic rock derived from granitic magma. Nutra-lite consists primarily of SiO_2 (70.0%) and Al_2O_3 (13.5%). This particulate also contains lesser (<5%) amounts of 11 other elements including Fe, Mg, and Ca. Preliminary observations of Canada geese on turf treated with Nutra-lite suggest that this particulate may also be effective as a tactile repellent (B. Wheeler, Montana Mineral Products, personal communication). Activated charcoal (20–60 mesh; CAS No. 64365-11-3) and white quartz sand (50–70 mesh; CAS No. 14808-60-7) were obtained from Sigma Chemical Company (St Louis, MO, USA).

Brown-headed cowbird aviary experiments

Adult male brown-headed cowbirds were captured in decoy traps in northern Ohio from March to June 1996 and transported to an outdoor aviary at the National Aeronautic and Space Administration Plum Brook Station (PBS), Erie County, OH. Cowbirds were held in groups in holding cages of 2.5 m × 2.5 m × 2.0 m in the outdoor aviary before the experiments and maintained as described by Belant *et al.* (1997). Twelve experimentally naive birds were used for each test (one- or two-choice) and repellent combination (a total of 96 birds) and were released after completion of the experiments.

Before each test, lime, charcoal, Nutra-lite, or sand was mechanically mixed with millet to achieve concentrations of 1.0%, 2.0%, or 4.0% (g g^{-1}) repellent. We used corn oil (10 ml kg^{-1}) to make repellents adhere to the millet. Untreated millet was mixed similarly with an equivalent amount of corn oil only.

Twelve birds were selected at random and housed individually in cages of 1.0 m × 1.5 m × 0.5 m containing water and millet. For 3 days immediately preceding the experiment, birds were provided with two cups (0.1 l) containing millet. Each cup was attached to a 24 cm diameter pan to catch spillage.

On day 1 of the 4 day test, cowbirds were weighed at 09:00 h and two food cups were placed in each cage. One cup contained 20.0 g of the millet–corn oil mixture and the other 20.0 g of millet–corn oil containing 1.0%, 2.0%, or 4.0% of a repellent. Treatments were assigned systematically to cages such that four replicates of each repellent and concentration occurred. Positions of cups in each cage were randomized. Cups were removed the following day at 09:00 h. The contents of removed cups, including spillage, were weighed to determine consumption. The 24 h consumption was adjusted for moisture gain or loss based on weight changes of control cups of millet and millet–repellent placed adjacent to cages. This procedure was repeated daily to day 4. Cowbirds were reweighed at 09:00 h on day 4.

Similar one-choice tests (four replicates per test) were also conducted for each repellent except that each cowbird received only one cup containing millet with 1.0%, 2.0%, or 4.0% repellent.

Consumption of food (g) was compared using one- or two-factor analysis of variance (ANOVA) with repeated measures (days) (SAS Institute, Inc., 1988). We assumed total millet consumption by two-choice groups was representative of birds consuming untreated millet only as these birds had about twice the untreated millet available than they could consume in 24 h. Thus, we used ANOVA to also compare total food consumption among one- and two-choice groups for each particulate evaluated. Tukey tests were used to isolate differences ($P<0.05$) among means. Changes in body mass of cowbirds for each test were compared using paired *t*-tests.

White-tailed deer feeding experiment

Treated corn was prepared in 31.8 kg batches using a cement mixer. Corn was tumbled dry for 1 min before adding corn oil (10 ml kg^{-1} corn) and one of the four repellents (4% g g^{-1}) and mixed for an additional 3 min. Untreated corn was mixed similarly but repellents were not added.

The experiments were conducted during August 1996 at the 2200 ha PBS. Characteristics of PBS have been described previously (Belant, Seamans and Dwyer, 1996a). During December 1995, PBS had an estimated minimum white-tailed deer population of 825 (≥38 km^{-2}) (P. Ruble, Ohio Div. Wildl., unpublished data).

We established eight deer feeding stations located ≥1 km apart using whole-kernel corn placed in two adjacent 1.2 m long cattle feed troughs. A 1.5 m high plastic fence was erected on three sides of a 5 m × 5 m area such that feed troughs were located inside the fenced areas about 1 m from the back. To monitor corn consumption, feed troughs were calibrated using wood stakes that were marked to measure corn at 4.6 kg intervals. A calibrated wood stake was positioned at each end of each trough. Thus, corn consumption was estimated to the nearest 2.3 kg. Corn was added to feed troughs as necessary to maintain a constant food supply and the amount of corn consumed was recorded.

To condition deer to use feeding stations we monitored each station 3–4 times a week for about 1 month before the experiment. The experiment consisted of two 4 day, two-choice tests. For the first test, four sites were selected at random to receive sand-treated corn; the remaining four sites received Nutra-lite-treated corn. At each site, we randomly selected one trough to receive 31.8 kg treated corn; the remaining trough received 31.8 kg untreated corn. We monitored each site once or twice daily, recording the amount of corn consumed and, if necessary, the amount of corn added. We determined the total amount of corn consumed in each trough at 24 h intervals for four consecutive days. The second test occurred 3 days after completion of the first test and was conducted identically except corn was treated with lime or charcoal.

We analyzed mean daily treated and untreated corn consumption for each repellent tested using one-factor ANOVA with repeated measures (days). To provide an index of relative consumption, we then determined the mean daily reduction in treated corn consumed relative to untreated corn consumed for each repellent and analyzed these data using ANOVA and Tukey tests.

Canada goose turf experiments

Adult-plumaged Canada geese of undetermined sex were captured during molt in northern Ohio during July 1996 and transported to a 2 ha fenced pond at PBS. A 0.4 ha fenced holding area adjacent to the pond was used to separate experimental from non-experimental geese. Geese were maintained as described by Belant *et al.* (1996b, 1997).

A fenced chute connected the holding area to the test site, which consisted of nine adjacent 10 m × 21 mm pens constructed of 1.5 m fence in a grass area. This area was sown with perennial rye and fertilized 4 weeks before testing. Each pen consisted of two 5 m × 21 m plots (treatment and control) delineated by a spray-painted line on the turf. A 0.5 m diameter pan of water was positioned in each plot adjacent to the fence midway on the long axis. Grass in pens was mowed to a height of 5 cm approximately every 7 days. A rain gauge was placed at the test site to monitor precipitation.

Lime. Before pretreatment conditioning, 16 geese were herded from the pond to the holding area and each was assigned randomly to one of four groups of four geese. We attached color-coded neck collars (one color per group) to individuals in each group. For 4 days before testing (13–16 July), the same 16 neck-collared geese were herded from the holding area to the test site and the same four geese were placed in each of the four pens at 09:00 h and allowed to graze until 16:00 h when they were herded back to the holding area. This grazing schedule allowed geese to adjust to pen conditions and establish social hierarchies before testing. Two vehicles used as observation blinds were positioned 10–15 m from the pens during pretreatment to ensure their presence did not modify goose behavior. Geese were assigned to non-adjacent pens such that groups were separated by ≥10 m.

The day before applying lime, grass in the pens was mown to a height of 5 cm and one plot in each pen was selected at random for treatment. The following morning at 07:00 h we applied lime on treatment plots using a push-operated rotary spreader at a rate of 270 kg ha^{-1}; remaining plots served as controls. The amount of lime used was 50% less than the amount previously reported to reduce grazing by geese (Belant *et al.*, 1997).

The day of lime application, two individuals in vehicles conducted observations of geese. Observations began daily at 09:00 h, immediately after geese were released into the pens. Each individual observed geese in each of two pens for 1 h, alternating observations between pens every 60 s (daily total of 30 min per pen). During each 60 s interval, observers recorded the number of geese observed initially in each plot, and the total number of bill contacts with grass in each plot. This procedure was repeated for four consecutive days.

To estimate fecal mass on each plot, we established a 1 m × 21 m transect through the center of each plot. We collected feces daily at 16:00 h from the transect in each plot during the treatment period. Feces were placed in a drying room at 38°C for 48 h before weighing. Fecal mass was converted to grams per plot for each plot by day of collection before analysis.

Mean numbers of geese observed, mean numbers of bill contacts, and mean mass of fecal material collected were analyzed using randomized block ANOVA with repeated measures. If main effects or interactions were significant ($P < 0.05$), we used Tukey tests to determine which means differed.

Nutra-lite. We began herding 16 experimentally naive geese into four untreated pens for pretreatment conditioning on 14 September. This experiment was conducted identically to the turf experiment with lime except that we applied Nutra-lite to treatment plots at the manufacturer-recommended rate of 2568 kg ha^{-1} and the experiment was conducted for 6 days.

Results

Brown-headed cowbird aviary experiments

Lime. Overall, total daily consumption of millet was similar ($P = 0.32$) for the six one- and two-choice groups (*Figure 1*). For two-choice groups, brown-

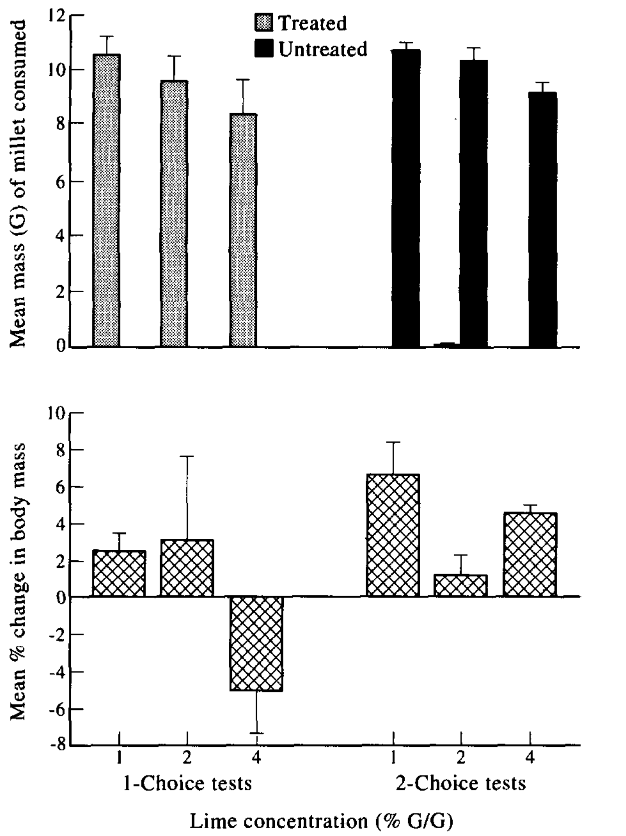

Figure 1. Mean daily (24 h) consumption of untreated and lime-treated millet by individual brown-headed cowbirds and mean percent change in body mass during 4 day, one- and two-choice tests, Erie County, OH, April 1996. Capped vertical lines represent 1 standard error

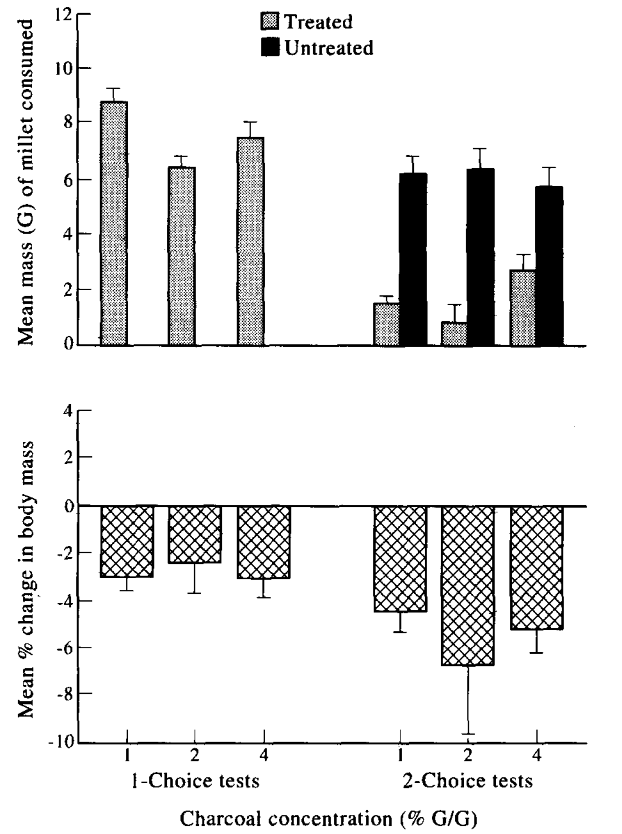

Figure 2. Mean daily (24 h) consumption of untreated and charcoal-treated millet by individual brown-headed cowbirds and mean percent change in body mass during 4 day, one- and two-choice tests, Erie County, OH, April 1996. Capped vertical lines represent 1 standard error

headed cowbirds consumed >99% less ($F = 1523.77$; 1,18 d.f.; $P < 0.01$) treated millet than untreated millet. There was no interaction ($P = 0.08$) of millet treatment and concentration for two-choice groups.

There was a day effect ($F = 24.77$; 3,27 d.f.; $P < 0.01$) for one-choice groups, with less millet consumed on day 1 [6.69 ± 1.27 g (mean $\pm$ SE)] than on days 2–4 ($\geq 9.62 \pm 1.20$ g). Cowbirds consumed less ($P < 0.05$) millet treated with 4% lime (4.45 ± 0.69 g) than millet with 1% lime (8.85 ± 1.02 g) on day 1; millet consumption among one-choice groups was similar ($P > 0.05$) for days 2–4.

Mean body mass of cowbirds in one-choice groups remained constant ($P \geq 0.08$). Mean body mass of cowbirds in two-choice groups remained constant (2% group; $P = 0.50$) or increased (1% and 4% groups; $t = 3.67$ and 9.00, 4 d.f., $P \leq 0.03$, respectively).

Charcoal. Overall, total daily consumption of millet was similar ($P = 0.06$) for the six one- and two-choice groups (*Figure 2*). For two-choice groups, brown-headed cowbirds consumed >53% less ($F = 34.68$; 1,18 d.f.; $P < 0.01$) treated millet than untreated millet. There was no interaction of concentration and millet treatment ($P = 0.41$). For one-choice groups, there was no difference ($P = 0.78$) in consumption among concentrations over days.

Mean body mass in the one-choice group with 1% charcoal and two-choice groups with 1% and 4% charcoal decreased ($t = -4.90$ to -5.20; 4 d.f.; $P \leq 0.02$). Body mass of the other groups remained constant ($P \geq 0.06$).

Nutra-lite. Overall, total daily consumption of millet was similar ($P = 0.29$) for the six one- and two-choice groups (*Figure 3*). For two-choice groups, brown-headed cowbirds consumed overall 60% less ($F = 14.48$; 1,18 d.f.; $P < 0.01$) treated millet than untreated millet. There was an interaction ($F = 6.87$; 2,18 d.f.; $P < 0.01$) of millet treatment and concentration. Consumption of millet treated with 2% or 4% Nutra-lite was ≥ 78% less than consumption of untreated millet ($P < 0.05$). In contrast, consumption of millet treated with 1% Nutra-lite (5.24 ± 0.29 g) was greater ($P < 0.05$) than consumption of untreated millet (3.88 ± 0.43 g).

There was a day effect ($F = 3.20$; 3,27 d.f.; $P = 0.04$) for one-choice groups, with consumption increasing up to day 3 then declining on day 4. There was no difference ($P = 0.61$) in consumption among groups over days.

Mean body mass of cowbirds in all groups remained constant ($P \geq 0.09$).

Sand. Overall, total daily consumption of millet was similar ($P = 0.89$) for the six one- and two-choice groups (*Figure 4*). For two-choice groups, brown-headed cowbirds consumed >14% less ($F = 15.06$; 1,18 d.f.; $P < 0.01$) treated millet than untreated millet. There was no interaction of concentration and millet treatment ($P = 0.11$). There was, however, an

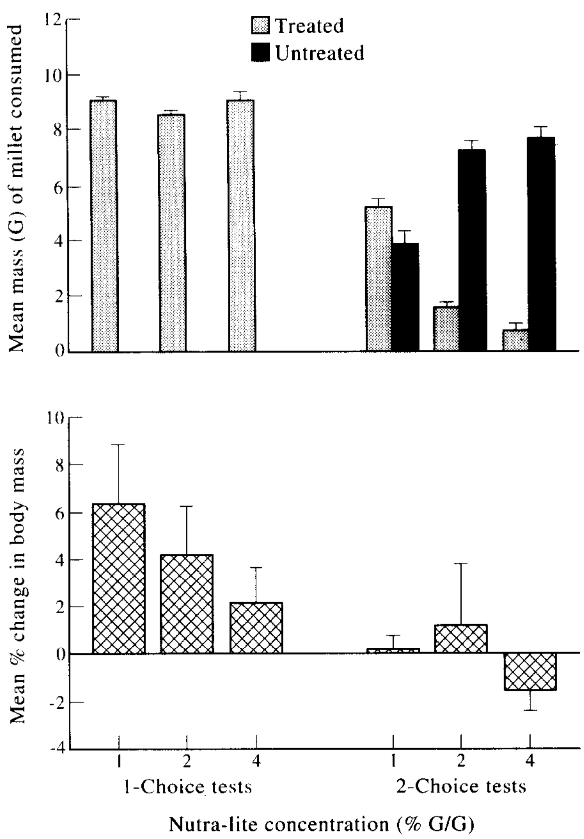

Figure 3. Mean daily (24 h) consumption of untreated and Nutra-lite-treated millet by individual brown-headed cowbirds and mean percent change in body mass during 4 day, one- and two-choice tests, Erie County, OH, June–July 1996. Capped vertical lines represent 1 standard error

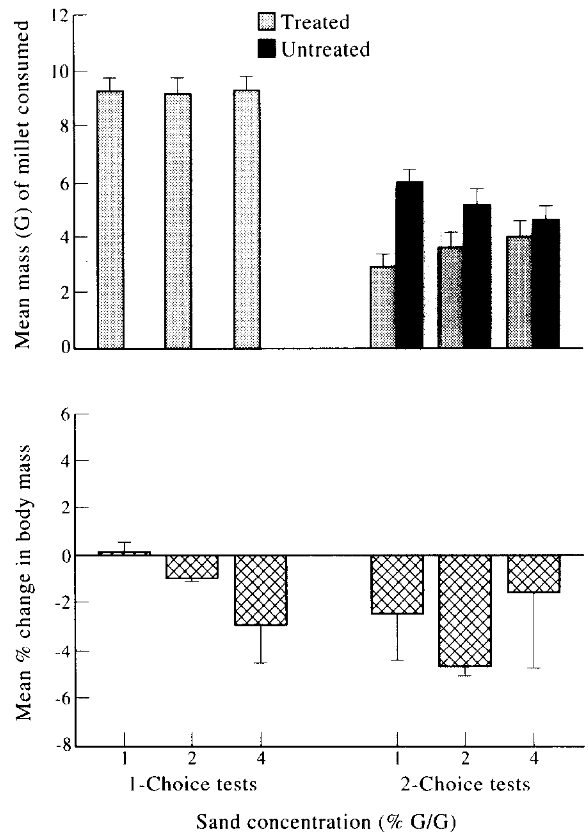

Figure 4. Mean daily (24 h) consumption of untreated and quartz-sand-treated millet by individual brown-headed cowbirds and mean percent change in body mass during 4 day, one- and two-choice tests, Erie County, OH, April–May 1996. Capped vertical lines represent 1 standard error

interaction of day and millet treatment ($F = 4.60$; 3,54 d.f.; $P < 0.01$), with less ($P < 0.05$) treated millet consumed on days 1 and 3, and similar ($P > 0.05$) amounts of treated and untreated millet consumed on days 2 and 4. For one-choice groups, there was no difference ($P = 0.61$) in consumption among concentrations over days.

Mean body mass of cowbirds in the two-choice group with 2% sand decreased ($t = -9.00$; 4 d.f.; $P \leq 0.01$). Body mass of the other groups remained constant ($P \geq 0.18$).

White-tailed deer feeding experiments

Corn treated with lime, charcoal, and Nutra-lite was consumed less ($F = 22.64$–111.86; 1,6 d.f.; $P < 0.01$) than was untreated corn (*Figure 5*). In contrast, there was no difference ($P = 0.44$) in consumption of sand-treated corn relative to untreated corn. There was no interaction of day and treatment ($P \geq 0.17$) for any of the repellents.

The mean daily percent reduction in corn consumption differed ($F = 33.08$; 3,12 d.f.; $P < 0.01$) among repellents tested. Lime (87% reduction) and charcoal (71% reduction) were equally effective ($P > 0.05$) in reducing deer consumption. These repellents caused greater reductions in consumption than did Nutra-lite ($P < 0.05$), which in turn was more effective ($P < 0.05$) than sand.

Canada goose turf experiments

Lime. There was no difference ($P = 0.18$) in the overall mean number of bill contacts observed on treated ($3.4 \pm 0.9\ \mathrm{min}^{-1}$) and untreated ($8.9 \pm 2.3\ \mathrm{min}^{-1}$) plots (*Figure 6*). There was no day effect or interaction of day and plot treatment ($P = 0.14$ and 0.21, respectively).

Mean numbers of geese observed on treated (1.6 ± 0.3) and untreated (2.4 ± 0.3) plots were similar ($P = 0.19$). There was an interaction ($F = 4.55$; 3,18 d.f.; $P = 0.02$) of day and plot treatment, with more geese ($P < 0.05$) observed on untreated plots on day 3. Mean fecal mass (g per 0.01 ha per 7 h) collected on treated (8.4 ± 3.7) and untreated (7.7 ± 2.6) plots was similar ($P > 0.90$). There was no day effect or day–plot treatment interaction ($P = 0.11$ and 0.18, respectively) for fecal mass.

We recorded 0.5, 0.5, 0.7, and 0.0 mm rain on day 1 to day 4, respectively. Lime was readily observed on turf on day 1 but difficult to distinguish visually from untreated plots on days 2–4.

Nutra-lite. The overall mean number of bill contacts observed on treated ($24.2 \pm 3.6\ \mathrm{min}^{-1}$) and untreated ($35.9 \pm 3.2\ \mathrm{min}^{-1}$) plots was similar ($P = 0.17$) (*Figure 7*). There was an interaction ($F = 4.37$; 5,30 d.f.; $P < 0.01$) of day and plot treatment, with more bill contacts ($P < 0.05$) observed on untreated plots on day 1. There was no day effect ($P = 0.50$).

The overall mean number of geese per observation on treated plots (1.4 ± 0.1) was less ($F = 12.02$; 1,6

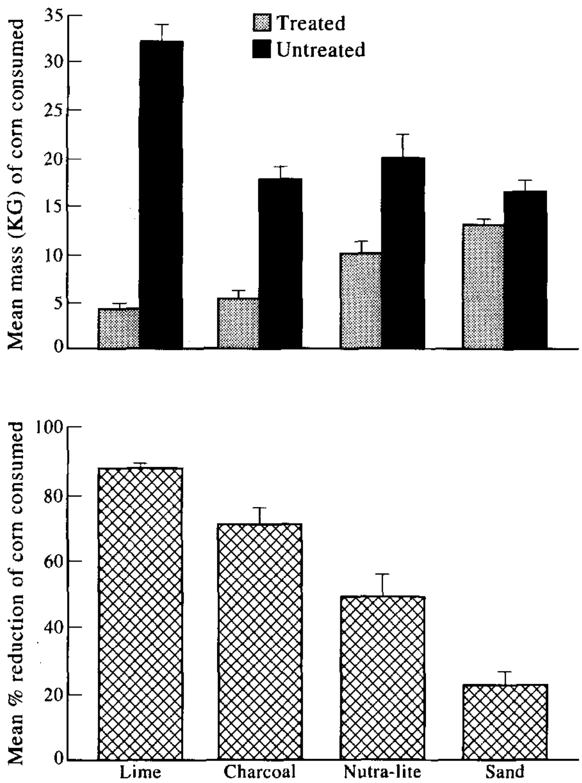

Figure 5. Mean daily (24 h) consumption of untreated and particulate-treated corn and mean daily percent reduction of particulate-treated corn consumed by white-tailed deer, Erie County, OH, August 1996. Capped vertical lines represent 1 standard error

d.f.; $P=0.01$) than the overall mean number observed on untreated plots (2.6 ± 0.1). There was an interaction of day and plot treatment ($F=3.74$; 5,30; d.f.; $P=0.01$), with fewer ($P<0.05$) geese observed on treated plots on days 1–3.

Overall mean fecal mass collected on treated (104.0 ± 22.6) and untreated (195.0 ± 30.4) plots was similar ($P=0.13$). There was more ($F=2.79$; 9,54 d.f.; $P<0.01$) fecal mass collected on day 4. There was no day-plot treatment interaction ($P=0.15$) for fecal mass.

We recorded 0.0, 10.5, and 0.2 mm rain on days 1–4, 5, and 6, respectively. Turf treated with Nutra-lite was completely covered and tan in color on day 1. Nutra-lite settled rapidly to the ground and was difficult to distinguish visually from untreated plots by day 4.

Discussion

The ranked relative effectiveness (from greatest to least) of particulates we tested for cowbirds and deer were lime, charcoal, Nutra-lite, and sand. Mason and Clark (1994) similarly ranked charcoal as more effective than sand for suppressing consumption by starlings. During two-choice tests, significant reductions in consumption of treated food typically occurred. During one-choice tests, however, no particulate at the concentrations tested reduced cowbird consumption relative to total consumption of millet in two-choice groups, with the exception of millet treated with 4% lime on day 1. In a comparable test, Belant *et al.* (1997) found significant reductions in consumption of millet treated with 25% lime for 2 days.

The fact that lime was as effective as, or more effective than the other particulates may be related to its basicity. The pH of lime used in this study was 11.7 (Genlime Group, Material Safety Data Sheet). Aversion by animals to caustic materials, such as strong basic compounds, is well documented. For example, in two-choice drinking tests, intake by chickens of hydroxide solutions with a pH of 12.0–12.2 was 33–36% less than intake of distilled water (Kare and Mason, 1986). Clark and Shah (1991) and Nolte *et al.* (1993) also demonstrated that isomers of acetophenone with greater basicity were more aversive to European starlings (*Sturnus vulgaris*) and house mice (*Mus musculus*), respectively, than were less basic isomers.

Cowbirds preferred millet treated with 1% Nutra-lite yet were repelled by Nutra-lite at greater concen-

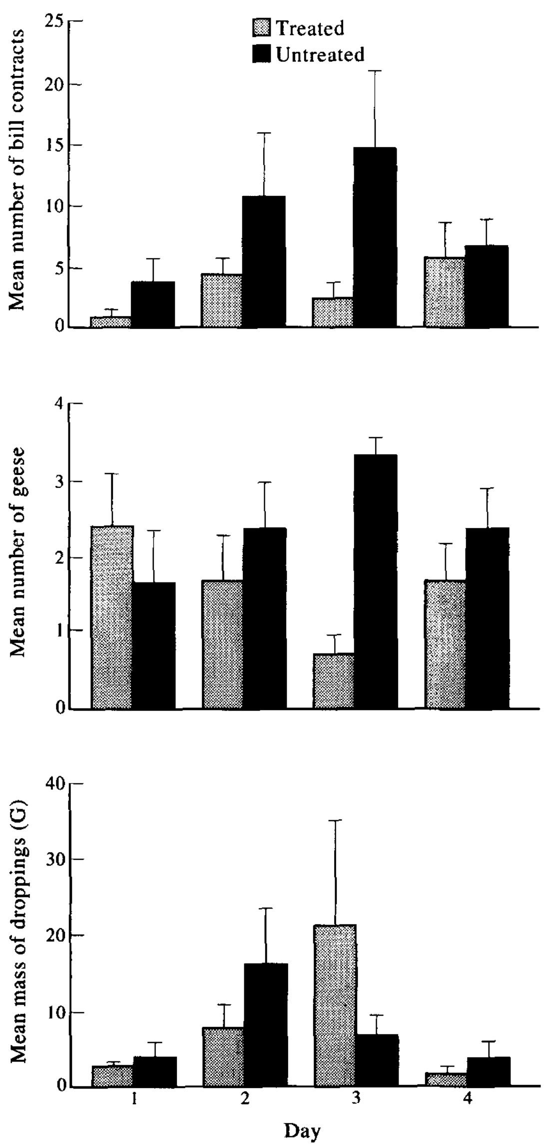

Figure 6. Mean number of bill contacts per four Canada geese per minute, number of geese per observation, and fecal mass per 0.01 ha per 7 h on grass plots untreated or treated with lime at an application rate of 270 kg ha^{-1}, Sandusky, OH, July 1996. Capped vertical lines represent 1 standard error

trations. It may be that cowbirds perceived millet treated with 2–4% Nutra-lite as grit and therefore limited their consumption (see Clark, 1995). The specific reason for this disparity remains obscure and would require additional experimentation.

Deer did not prefer Nutra-lite over untreated corn; however, the numerical trend was for relatively greater consumption of Nutra-lite than of corn treated with lime or charcoal. Deer have specific Ca requirements for optimal development (Magruder *et al.*, 1957; Ullrey *et al.*, 1973, 1975). Although amounts of Ca present in white-tailed deer forage appear adequate throughout much of their range, deer do seek Ca in geophageous activity (Jones and Hanson, 1985). In addition, body mass of fawn deer from areas with calcareous soils is greater than that of fawns from areas without calcareous soils (Jones and Hanson, 1985). As with cowbirds, the fact that deer did not consume lime-treated corn for nutritional benefits was probably due to its basicity.

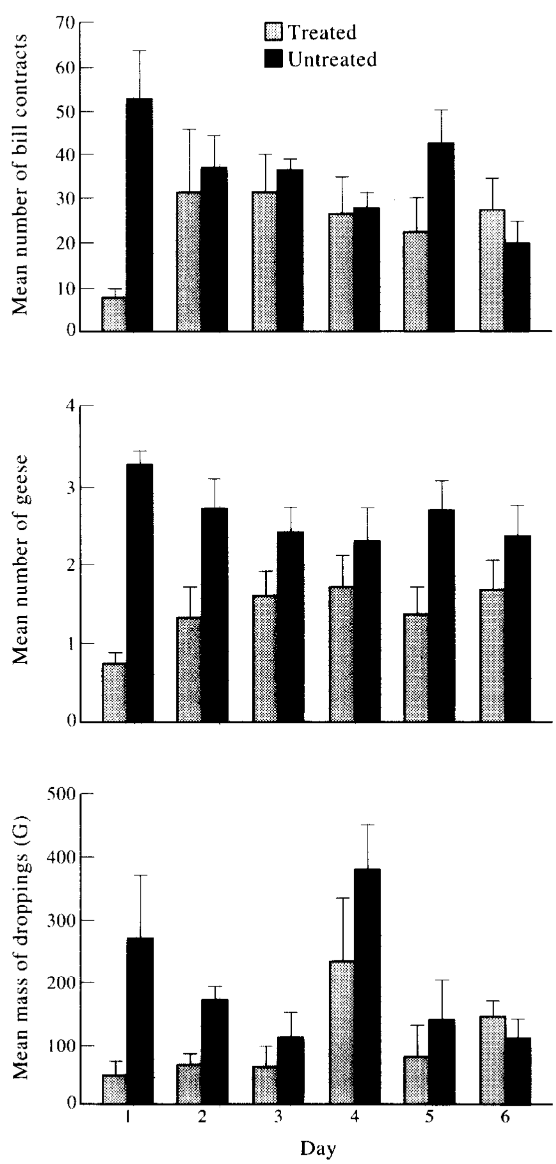

Figure 7. Mean number of bill contacts per four Canada geese per minute, number of geese per observation, and fecal mass per 0.01 ha per 7 h on grass plots untreated or treated with Nutra-lite at an application rate of 2268 kg ha^{-1}, Sandusky, OH, August 1996. Capped vertical lines represent 1 standard error

In contrast to lime- and charcoal-treated feed, the appearance of millet and corn treated with Nutra-lite and sand was not readily distinguishable from untreated materials. Birds can display avoidance or preference for colors (Hess, 1956; Reidinger and Mason, 1983), although neophobia to black and white pigments has not been demonstrated (Dolbeer *et al.*, 1992; Mason and Clark, 1994, 1996; Rodriguez, 1988). Nonetheless, the possibility exists that cowbirds and deer exhibited neophobic responses to feed treated with lime and charcoal which could enhance repellency. A more plausible explanation is that the color of lime and charcoal served as visual cues, which animals associated with the particulates, enhancing repellency. Mason and Clark (1996) suggested that any color that contrasts against its background could function as a visual cue.

In this study, Canada geese were not repelled by lime applied to turf at an application rate of 270 kg ha^{-1}. In a similar experiment, Belant *et al.* (1997) reduced goose grazing of turf treated with 544 kg ha^{-1} lime for 2 or 3 days. Using activated charcoal at a rate of 3.4 kg ha^{-1}, Mason and Clark (1995) reported suppressing snow goose activity in winter wheat and Kentucky bluegrass plots for 16 days. As lime performed at least as well as charcoal in controlled tests with both cowbirds and deer in this study, it is unclear why charcoal performed better than lime in previous studies (Belant *et al.*, 1997; Mason and Clark, 1995). Snow geese may be more susceptible to particulate repellents than are Canada geese. Also, it could be a consequence of Mason and Clark (1995) using a binding agent, which would improve adherence of the particulate to vegetation and enhance repellency by increasing the amount of particulate contacted by geese.

Canada geese were deterred from grazing on turf treated with Nutra-lite for 1 day and were observed less frequently on treated plots for 3 days post-application. That geese did not graze as frequently on treated turf during the first day is not surprising; we speculate that virtually any non-food material applied to turf at about 2600 kg ha^{-1} would be less palatable to geese than untreated turf. That geese initially were observed less frequently on treated turf suggests that a slight tactile aversion to Nutra-lite exists, possibly a consequence of the abrasiveness of the material to their feet.

Management implications

There are several potential practical applications for use of lime and possibly activated charcoal. For example, these materials may be suitable for application to agricultural crops, particularly during sprouting stages. This is especially true for lime, which is already commonly used in agricultural practices to increase soil pH. On soils requiring an increase in alkalinity, altering the time of lime application could be advantageous. For example, in northern Ohio, farmers apply 4500 kg ha^{-1} of lime to acidic soils during tillage every 3–5 years (B. Hudson, Ohio Agricultural Extension Office, personal communication). Assuming an average annual application rate of $1100\,kg\,ha^{-1}$, conducting two $550\,kg\,ha^{-1}$ applications at 1 week intervals to sprouting crops (e.g. sprouting soybeans or corn) may reduce crop depredations and increase soil basicity. This rate ($550\,kg\,ha^{-1}$) of applying lime has been used previously to reduce goose grazing on turf (Belant *et al.*, 1997). Because activated charcoal is visually less conspicuous, it could be used to reduce wildlife use of turf where lime is undesirable, such as on corporate lawns.

Because soil in many parts of the western USA is alkaline, particularly in semi-arid and arid regions, applying lime to reduce depredations by wildlife would not be practical. Gypsum, sulfur, or lime–sulfur products are used typically to maintain an appropriate pH. Research evaluating the efficacy of these and similar products to reduce wildlife grazing of agricultural crops appears warranted.

Another possible application for the repellents tested is at landfills. Lime (and possibly charcoal) could be applied in powder or slurry form to reduce feeding by birds on exposed refuse. Alternatively, the compounds could be incorporated into landfill cover materials to prevent birds from gaining access to the covered refuse (see Dolbeer *et al.*, 1993).

Lime is an inexpensive, readily available compound that is used frequently in agriculture and turf management in the eastern USA. Activated charcoal is an environmentally safe and stable compound (Mason and Clark, 1994). These compounds should not pose a hazard to wildlife or the environment. Therefore, registration costs of these compounds should be low relative to many other potential repellents. Additional studies of lime and charcoal as wildlife feeding repellents are warranted; in particular, field studies to determine minimum effective concentrations, duration of repellency, and cost-effectiveness should be carried out.

Acknowledgements

A.L. Bower, PBS, granted permission to use study sites. We thank Ohio Division of Wildlife personnel and A.J. Montoney for providing geese. Nutra-lite was provided by B. Wheeler (Montana Mineral Products). C.R. Bartholomew and G.E. Bernhardt provided field assistance; L. Clark and R.A. Dolbeer reviewed an earlier draft of this manuscript. Funding and support was provided by the Federal Aviation Administration (FAA), Office of Airport Safety and Standards, Washington, DC, and Airports Division, Airport Technology Branch, FAA Technical Center, Atlantic City International Airport, NJ. Procedures used involving animals were approved by the National Wildlife Research Center Animal Care and Use Committee.

References

Ankney, C. D. (1996) An embarrassment of riches: too many geese. *J. Wildl. Manage.* **60**, 217–223

Babcock, K. M., Humburg, D. D. and Graber, D. A. (1990) Goose management: the Mississippi Flyway perspective. *Trans. N. Am. Wildl. Nat. Resour. Conf.* **55**, 313–320

Belant, J. L., Seamans, T. W. and Dwyer, C. P. (1996) Evaluation of propane exploders as white-tailed deer deterrents. *Crop Protect.* **15**, 575–578

Belant, J. L., Seamans, T. W., Tyson, L. A. and Ickes, S. K. (1996) Repellency of methyl anthranilate to pre-exposed and naive Canada geese. *J. Wildl. Manage.* **60**, 923–928

Belant, J. L., Tyson, L. A., Seamans, T. W. and Ickes, S. K. (1997) Evaluation of lime as an avian feeding repellent. *J. Wildl. Manage.* **61**

Best, L. B. and Gionfriddo, J. P. (1994) House sparrow preferential consumption of carriers used for pesticide granules. *Environ. Toxicol. Chem.* **13**, 919–925

Clark, L. (1995) Effects of particle size on starling preference for food coated with activated charcoal. *Crop Protect.* **14**, 461–465

Clark, L. and Shah, P. S. (1991) Nonlethal bird repellents: in search of a general model relating repellency and chemical structure. *J. Wildl. Manage.* **55**, 538–545

Cleary, E. C. (1994) Waterfowl. In *Prevention and Control of Wildlife Damage*, eds S. E. Hygnstrom, R. M. Timm and G. E. Larson, pp. E129–E138. Univ. Nebraska Coop. Ext. Serv., Lincoln

Cleary, E. C., Wright, S. E. and Dolbeer, R. A. (1997) Wildlife Strikes to Civilian Aircraft in the United States 1993–1995. Fed. Aviation Admin. Ser. Rep. 2, Washington, DC, 33 pp

Craven, S. R. and Hygnstrom, S. E. (1994) Deer. In *Prevention and Control of Wildlife Damage*, eds S. E. Hygnstrom, R. M. Timm and G. E. Larson, pp. D25–D40. Univ. Nebraska Coop. Ext. Serv., Lincoln

Decker, D. G. and Avery, M. L. (1990) Reducing blackbird damage to newly planted rice with nontoxic clay-based seed coating. *Proc. Vertebr. Pest Conf.* **14**, 327–331

Dolbeer, R. A. (1994) Blackbirds. In *Prevention and Control of Wildlife Damage*, eds S. E. Hygnstrom, R. M. Timm and G. E. Larson, pp. E25–E32. Univ. Nebraska Coop. Ext. Serv., Lincoln

Dolbeer, R. A., Belant, J. L. and Clark, L. (1993) Methyl anthranilate formulations to repel birds from water at airports and food at landfills. *Proc. Great Plains Wildl. Damage Control Workshop* **11**, 42–53

Dolbeer, R. A., Holler, N. R. and Hawthorne, D. W. (1994) Identification and control of wildlife damage. In *Research and Management Techniques for Wildlife and Habitats*, ed. T. A. Bookhout, pp. 474–506. The Wildl. Soc., Bethesda, MD

Dolbeer, R. A. and Ickes, S. K. (1994) Red-winged blackbird feeding preferences and response to wild rice treated with Portland cement or plaster. *Proc. Vertebr. Pest Conf.* **16**, 279–282

Dolbeer, R. A., Woronecki, P. P. and Bullard, R. W. (1992) Visual cue fails to enhance bird repellency of methiocarb in ripening sorghum. In *Chemical Signals in Vertebrates, VI*, eds D. Muller-Schwarze, R. Silverstein and D. Doty, pp. 323–330. Plenum, New York

Gladfelter, J. L. (1984) Midwest agricultural region. In *White-tailed Deer Ecology and Management*, ed. L. K. Halls, pp. 427–440. Stackpole Books, Harrisburg, PA

Hess, E. H. (1956) Natural preferences of chicks and ducklings for objects of different colours. *Physiol. Rep.* **2**, 477–483

Jacobson, H. A. and Kroll, J. C. (1997) The white-tailed deer — the most managed and mismanaged species. *Int. Congr. Bio. Deer* **3**

Jones, R. L. and Hanson, H. C. (1985) *Mineral Licks, Geophagy, and Biogeochemistry of North American Ungulates*. Iowa State Univ. Press, Ames, 301 pp

Kare, M. R. and Mason, J. R. (1986) The chemical senses in birds. In *Avian Physiology*, ed. P. D. Sturkie, pp. 59–74. Springer-Verlag, New York

Magruder, N. D., French, C. E., McEwwn, L. C. and Swift, R. W. (1957) *Nutritional Requirements of White-tailed Deer for Growth and Antler Development. II. Pa. Agric. Exp. Stn. Bull.* **628**

Marsh, R. E., Erickson, W. A. and Salmon, T. P. (1991) *Bird Hazing and Frightening Methods and Techniques*. Calif. Dep. Water Resour., Contract No. B-57211, 233 pp

Mason, J. R. and Clark, L. (1992) Nonlethal repellents: the development of cost-effective, practical solutions to agriculture and industrial problems. *Proc. Vertebr. Pest Conf.* **15**, 115–129

Mason, J. R. and Clark, L. (1994) Use of activated charcoal and other particulate substances as feed additives to suppress bird feeding. *Crop Protect.* **13**, 213–224

Mason, J. R. and Clark, L. (1995) Evaluation of methyl anthranilate and activated charcoal as snow goose grazing deterrents. *Crop Protect.* **14**, 467–469

Mason, J. R. and Clark, L. (1996) Grazing repellency of methyl anthranilate to snow geese is enhanced by a visual cue. *Crop Protect.* **15**, 97–100

Nolte, D. L., Mason, J. R. and Clark, L. (1993) Nonlethal rodent repellents: differences in chemical structure and efficacy from nonlethal bird repellent. *J. Chem. Ecol.* **19**, 2019–2027

Peterjohn, B. G., Sauer, J. R. and Link, W. A. (1994) The 1992 and 1993 summary of the North American Breeding Bird Survey. *Bird Popul.* **2**, 46–61

Reidinger, R. F. and Mason, J. R. (1983) Exploitable characteristics of neophobia and food aversions for improvements in rodent and bird control. *Vertebrate Pest Control and Management Materials: 4th Symposium*, ed. D. E. Kaukeinen, pp. 20–42. American Society for Testing and Materials, Philadelphia, PA

Rodriguez, E. (1988) Use of calcium carbonate to minimize dosage of the avian repellent methiocarb. M.S. Thesis, Colorado State University, Fort Collins, Colorado, 37 pp

SAS Institute, Inc. (1988) *SAS/STAT User's Guide*, Statistical Analysis Systems Institute, Inc., Cary, NC, 1028 pp

Ullrey, D. E., Youatt, W. G., Fay, L. D., Schoepke, B. L., Magee, T. W. and Keahey, K. K. (1973) Calcium requirements of weaned white-tailed deer fawns. *J. Wildl. Manage.* **37**, 187–194

Ullrey, D. E., Youatt, W. G., Johnson, H. E., Cowan, A. B., Fay, L. D., Covert, R. L., Magee, W. T. and Keahey, K. K. (1975) Phosphorus requirements of weaned white-tailed deer. *J. Wildl. Manage.* **39**, 590–595

Wright, S. E. (1996) Watch out for Rudolph! *FAA Aviation News* **35**(8), 19–23

Received 3 December 1996
Revised 3 February 1997
Accepted 4 February 1997